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Commodity Treatments:

Responses of Nectarines Peaches, and Plums to Fumigation With Methyl Bromide

Abstract

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Symptoms of methyl bromide injury are slight to severe brown blotchy areas on peaches, slight to severe pitting and browning of nectarines, and localized brown or purple discoloration and pitting of plums. Fumigation did not significantly affect weight loss under our experimental conditions.

Injury generally increased with increasing dosage of methyl bromide, and the rate of ripening subsequent to treatment generally was slowed as the dosage increased. The effect on ripening was particularly apparent in plums, which change color as they ripen, but also was apparent in nectarines and peaches, which change firmness with ripening. Less injury occurred at high (26.5°C) than at low (4.5°C) temperature, and less injury occurred in field-run fruit than in fruit fumigated after packinghouse handling. Individual cultivars of nectarines, peaches, and plums differed greatly in their susceptibility to injury from methyl bromide fumigation.

Inorganic bromide residues were less than 10 parts per million (p/m) in nectarines and plums and less than 12 p/m in peaches fumigated with dosages up to 48 g/m^3 methyl bromide. Organic bromide residues in all three fruits were less than 5.0 p/m after 2 days and less than 0.30 p/m after 7 days in cold storage.

Preface

This research report is the first of a series of reports on the efficacy of quarantine treatments against various insect pests and on phytotoxicity in treated commodities. The research is in response to a need to develop fumigation treatments for fresh fruits and vegetables to control possible codling moth (*Cydia pomonella* L.) infestations in fruit destined for export. The research has the combined goal of meeting quarantine requirements of countries that receive U.S. agricultural exports and of improving quarantine treatments for products imported into the United States. These products carry with them a continuing threat of introduction of various insect pests, such as the Mediterranean fruit fly.

The commodity treatment research was cooperative between the Stored Product Insects Research Laboratory (SPIRL) and the Market Quality and Transportation Research Laboratory (MQ&TRL), Fresno, Calif. Fumigations were conducted and residue determinations were made at SPIRL, where a concurrent study was underway on the efficacy of methyl bromide treatments against codling moth. Treated fruit was held under simulated transport conditions at MQ&TRL, where subsequent quality evaluations were made and phytotoxic responses to the fumigations were determined. The staffs of both laboratories participated in sample preparation and data analysis.

Acknowledgments

The cooperation and support of the members and staff of the California Tree Fruit Agreement, Sacramento, are gratefully acknowledged. We also thank Howard K. Nelson, research leader, Stored Product Insects Research Laboratory, Fresno, Calif., for his contributions to the planning of fumigation treatments and to related research on the efficacy of these treatments against the codling moth. This research will be reported separately by Nelson and coworkers.

Keywords: Fumigation, phytotoxicity, methyl bromide, stone fruits, peaches, plums, nectarines, residues, handling practices, sorption, ripening, export, quarantine treatments, codling moth, *Cydia pomonella,* commodity treatments.

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Contents

Commodity Treatments: Responses of Nectarines, Peaches, and Plums to Fumigation with Methyl Bromide

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Background

Quarantine restrictions against insects have limited U.S. exports of fresh fruits and vegetables to Asian, European, and other overseas markets. The development of effective fumigation treatments for cherries exported from the Northwest has opened new markets for this crop in areas where quarantines against codling moth, *Cydia pomonella* L., have prevented its export. Entry of other stone fruits into overseas markets where quarantines apply would be possible if effective and acceptable fumigation treatments were developed.

An acceptable fumigant for control of insects is one that will eliminate an insect infestation, but will not injure the host fruit. Neither should the fumigant impart residues in excess of legal tolerances nor should it present unwarrantable hazards to applicators. Methyl bromide (MB) appears to meet most of these requirements for many commodities if applied at the proper dosage and under prescribed conditions (*8, 9*).[2] The effects of MB as a fumigant against various stages of the codling moth in apples were investigated by Isaac (*15*), Moffitt (*21*), and Morgan et al. (*23*), and in pears by Mackie and Carter (*20*). The tolerance of many deciduous fruits to MB and other fumigants was studied by Claypool and Vines (*7*). MB as a quarantine treatment of cherries for disinfestation from codling moth also has been investigated (*2, 3, 22*), and a fumigation schedule for control of this insect on cherries was subsequently established by the Animal and Plant Health Inspection Service, U.S. Department of Agriculture (*1*). MB is regularly used as a fumigant for various stone fruits exported to Canada.

Phytotoxic responses of deciduous fruits to MB fumigation have been described as off-flavors, flesh browning, flesh breakdown, accelerated or delayed ripening, enhanced redness, increased scalding and browning of the fruit surfaces, spotting, pitting, and/or increased decay (*5, 6, 7, 16, 17*). Increased respiration rates in some fumigated fruits are an indication of a shortened storage or shelf life (*6*) that may result from MB treatment. In some fruits, there is a negative correlation between MB dosage and ripening rate (*7, 19*).

The temperature of fruits and vegetables during fumigation may affect the degree and incidence of damage from MB. Generally, more injury occurs at lower than at higher temperatures (*25, 26*).

The phytotoxicity of MB obviously is affected by the concentration of the fumigant and the length of exposure to it. Many California fruits have been found to tolerate dosages (that amount of MB applied at beginning of the exposure period) up to 32 g/m^3 for 2 hr, but higher dosages or longer exposures often cause injury (*7*).

Fruit responses to fumigation are sometimes affected by postharvest applications of other chemicals. For example, diphenylamine, applied to Granny Smith apples as a scald inhibitor, also prevents or reduces injury from subsequent MB fumigation of this fruit (*31*). On the other hand, certain packinghouse applications of waxes and fungicides appear to increase the susceptibility of citrus fruit to fumigation injury (unpublished data).

Various cultivars of fruit may differ considerably in their tolerance to MB (*7, 15, 17, 24*). Many of the stone fruit cultivars studied in the late forties and early fifties have been replaced by newly developed cultivars. Consequently, phytotoxicity data are not available for most cultivars of nectarine [*Prunus persica* (L.) Batsch var. *nectarina* (Ait.) Maxim.] now in production and are available for only a few of the current peach [*P. persica* (L.) Batsch] and plum [*P. salicina* Lindl.] cultivars.

Since insect mortality is based on fumigant concentration and time, the sorption characteristics of the commodities being fumigated must be studied. The sorptive capacity of a commodity must be defined to satisfy the need for maintaining an effective concentration of the fumigant (*29*). Sorption by the commodity is affected by sorption of the fumigation chamber itself, the quantity and nature of the produce in the chamber (load factor), packaging materials, time, and temperature.

Comprehensive studies of residues in many fruits and vegetables fumigated with MB (*8*) show that peaches and plums have a very low rate of residue accumulation, in comparison with other fruits. No residue work, however, has been reported on many of the new cultivars of peaches and plums now in commercial production, and a search of the literature did not reveal any bromide residue data on nectarines.

Bromide residues may be organic or inorganic. The significance of these different forms of bromide has been investigated (*10, 14*), and analytical methods for determining organic bromides in small amounts have been developed (*4, 11, 12, 13, 18, 28, 30*). Researchers regularly determine organic bromide residues after all

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[2]Italic numbers in parentheses refer to Literature Cited, p. 10.

fumigations, so the desorption rate of the fumigant is known for each commodity when fumigated under various conditions.

The objectives of this research were to determine:

(1) The tolerance of phytotoxic responses of the most important commercial cultivars of nectarines, peaches, and plums to the fumigation treatment; (2) the effects of temperature on phytotoxicity; (3) the effects of dosage of the fumigant and time on phytotoxicity; (4) the effects of packinghouse handling on the responses of fruit to fumigation treatment; (5) sorption of MB under various fumigation conditions; (6) organic and inorganic bromide residues in various cultivars of fruit; and (7) effects of fumigation treatments on ripening, shelf life, and storability of the various stone fruits.

A concurrent study was conducted to determine the efficacy of various fumigation treatments against the codling moth. This research will be reported separately.

Materials and Methods

Sample collection

Test fruit were obtained from commercial packing facilities in the central San Joaquin Valley of California. The selection of nectarine, peach, and plum cultivars was based on (1) the commercial importance of the cultivar; (2) the harvest date for the cultivar; and (3) the export potential of the cultivar in relation to other available cultivars. The cultivars selected for fumigation and their harvest dates are listed in table 1.

One sample of each cultivar was selected from the field bins prior to packing. The other sample was obtained after fruit from the same lot had passed through the packing line and had been commercially packed. Most of the packinghouse lots, therefore, had been washed, waxed, treated with a fungicide, and sorted although some lots of plums were not washed and waxed. All lots were held in commercial shipping boxes, except during fumigation.

The fruit samples were transported by refrigerated truck from the packing facility to the laboratory where they were held at 0°C until they were scheduled for treatment. Most fruit were fumigated within a day or two of harvest, but a few lots were held longer. All fruit were conditioned by warming them to the temperature desired during fumigation.

Fumigation treatments

The laboratory fumatoriums were either 20- or 29-liter glass battery jars with aluminum lids. Rubber stoppers with glass sleeves were positioned through holes in the lids as ports for MB application and withdrawal. The undersides of the lids were fitted with small, battery-powered, electric fans to circulate the air and to provide uniform distribution of MB within the jars. The lids were sealed with closed-cell neoprene gaskets.

In 1978, the fumigation treatments consisted of four concentrations of MB at three temperatures, plus a control lot at each temperature. The MB dosages were 0, 32, 48, 64, or 80 g/m^3, and the fruit temperatures during fumigation were 4.5°, 15.5° or 26.5°C ± 1.0° for each dosage. All treatments lasted 2 hr.

In 1979, the 2-hr treatments were made at the following temperatures and dosages of MB:

°C	G/m^3
4.5° ± 1.0°	0, 48, 64 and 80
15.5° ± 1.0°	0, 32, 48 and 64
26.5° ± 1.0°	0, 16, 32 and 48

The dosages and temperatures were designed to bracket the ranges in which phytotoxicity from MB might occur and be clearly identified.

In 1980, a single MB dosage of 48 g/m^3 at 15.5°C ± 1.0° for 2 hr was used for the phytotoxicity studies. This relatively strong treatment was chosen because the codling moth does not occur in Japan (*27*) and is considered a "quarantine" insect. Consequently, a treatment with a high level of confidence was sought.

Each chamber contained 104 fruit of which 100 were required for evaluation of quality and 4 for residue analysis. Since 104 fruit were required per chamber, no attempt was made to adjust the chamber load, which

Table 1—Cultivars and harvest dates of stone fruit fumigated in 1978, 1979, and 1980

Nectarine		Peach		Plum	
Cultivar	Date	Cultivar	Date	Cultivar	Date
May Grand[2]	6/10	Springcrest[2]	6/04	Red Beaut[2]	5/31
Red Diamond[3]	6/26	Red Top[2]	7/08	Laroda[1]	7/20
Spring Red[2]	7/01	Coronet[1]	6/19	Santa Rosa[1 2]	6/17–24
Summer Grand[1]	7/06	Fayette[1]	8/07	Kelsey[2]	7/25
Fantasia[1 2]	7/22–24	O'Henry[2]	8/21	Casselman[1 2]	8/05–17
Flamekist[2]	8/13			Friar[3]	8/05
Fairlane[1]	8/28				

[1]Treated in 1978 season.
[2]Treated in 1979 season.
[3]Treated in 1980 season.

varied with the size of the fruit and ranged from 45 to 90 percent. The application of MB was accomplished by introducing the appropriate amount into each chamber as a gas derived from special MB gas cylinders via a large-volume gas syringe.

After fumigation, all chambers were aerated for 2 hr, at which time four fruit were removed for analysis of bromide residues. The remaining 100 fruit were returned to the packing boxes and stored at 2.5°C for later quality evaluation.

Sorption determinations

To obtain concentration vs. time data (sorption) during fumigation, gas samples were withdrawn from each chamber with a 50-ml gas syringe immediately after introducing the gas and after 30, 60, and 120 min. Concentrations of MB were determined with a Tracor 550 gas/liquid chromatograph (GLC). The column was 1.8 m by 4 mm I.D. nickel, packed with 10 percent DC-200 on Gas Chrom Q 100/120 mesh. The oven temperature was 100°C, the flame ionization detector was 200°, and the gas sampling valve with a 0.10-ml sample loop was held at 110°. The flow rate of the nitrogen carrier gas was 50 ml/min.

Residue analysis

Fruit for inorganic bromide residues were stored at -23.5°C. Only the pulp and skin were analyzed, using a modification of the procedure by Shrader et al. (*28*). In this procedure, the inorganic bromide breakdown products are detected and calculated as parts per million bromide ion. The bromide is extracted from macerated tissue, using water as the solvent, and the extraneous organic material from the commodity is eliminated by ashing. The inorganic bromide is determined by oxidation and titration.

Organic bromide residue was determined by a method developed for grapefruit (*18*) and adapted at our laboratory for organic bromide residues in other commodities. In this method, the commodity is macerated with water in a 500-ml Eberbach blender at high speed. The blender lid is equipped with a Luer-Lok stainless steel stopcock to accept a gas syringe. From 15 to 20 min after blending, a gas sample is withdrawn from the headspace and injected into a GLC equipped with an electron-capture detector. The GLC is calibrated by adding known amounts of gaseous MB to untreated fruit and carrying it through the same procedure as that for the sample analyzed. Because the sample is injected as a gas, cleanup is not needed. In this respect, this method eliminates many of the problems associated with solvent extraction methods.

To verify the appropriateness of this method, we compared it with solvent extraction methods, such as those developed by Heuser et al. (*13*), and found it to be more rapid and accurate, especially for fresh fruits.

A sample of three fruit was taken from each treatment; one fruit was analyzed for organic bromides after 2 hr aeration, one fruit after 2 days, and the other after 7 days. The 2- and 7-day samples were held at 2.5°C to simulate the temperature during transit to the Far East. The organic bromide residues were negligible after 7 days, so no further analyses were made.

Quality evaluation

Fruit from each fumigation treatment were stored loosely in the commercial shipping boxes at 2.5°C for 2 weeks to simulate the time required for export, after which they were examined. A second examination was made after holding an additional 2 days at 21° to simulate marketing conditions. Quality evaluation included determination of the percentage decay; rating of injured fruit for discoloration, pitting, or other defects; weight loss; and other factors, such as delayed ripening. Ripeness was rated on the basis of visual color changes in the fruit, firmness was measured on a U.C. Firmness Tester with a 5/16-inch (7.9 mm) diameter plunger, and soluble-solids content was measured with a temperature-compensated, hand refractometer.

Results

Residues

Sorption of MB during fumigation. At an MB dosage of 48 g/m³ and a load factor of 50 to 70 percent, the sorption of MB was more pronounced during the first ½ to 1 hr by peaches and nectarines than by plums (fig. 1). The sorption by the plums was more gradual; invariably they sorbed less than either peaches or nectarines. When apples were fumigated, losses of MB due to sorption ranged from 18.4 to 28.4 percent (*22*), but these losses

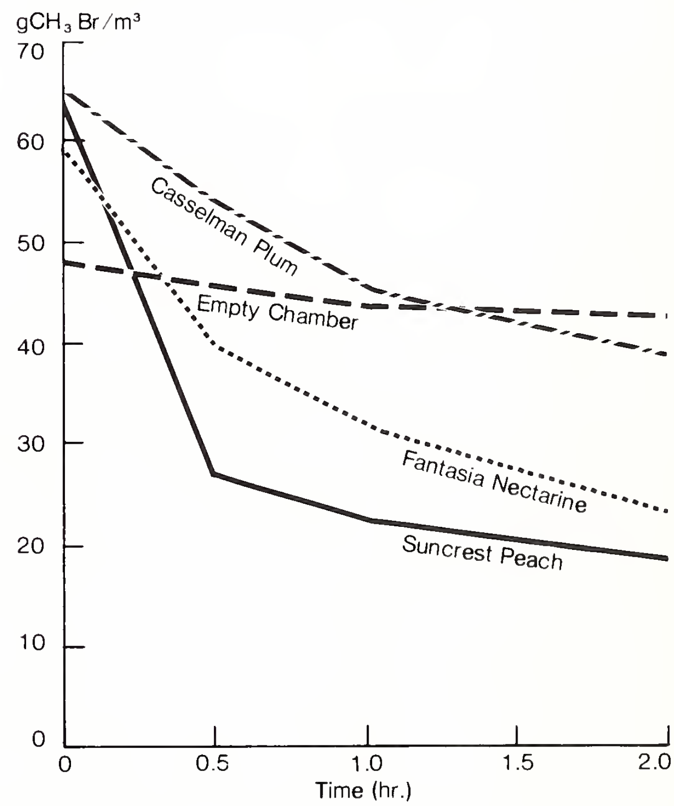

Figure 1.—Concentration of methyl bromide remaining in free air space during fumigation of nectarines, peaches, and plums (dosage = 48 g/m³, 2 hr, load factor 50 to 55 percent).

did not significantly reduce the efficacy of the fumigant. The sorption of MB by peaches (62.2 percent), nectarines (57.7 percent), and plums (34.6 percent) under similar conditions was greater than that for apples. Temperature during fumigation had only a slight effect on sorption.

Inorganic bromide residues. At MB dosages of 32, 48, and 64 g/m^3, all inorganic bromide residues were less than the U.S. tolerance of 10 p/m (table 2). At 80 g/m^3, only one sample of Fayette peaches had 20 p/m inorganic bromide (Appendix table 1), but the average for all peach varieties was below the tolerance. At a realistic commercial dosage of 32 or 48 g/m^3, nectarine (Appendix table 2) and plum (Appendix table 3) residues were all less than 10 p/m, and those for peaches were no greater than 12 p/m. Overall, plums had the lower residues, which corresponded with their lower capacity to sorb MB during fumigation than nectarines or peaches. As expected, when the dosage was increased, inorganic bromide residue also increased.

Organic bromide residues. Residual MB was desorbed rapidly from peaches (table 3) and nectarines (table 4), but less rapidly from plums (table 5). After 2 hr aeration, plums retained more MB than peaches or nectarines and, consequently, had slightly higher organic residues after 2 and 7 days of storage. After 2 days in cold storage (2.5°C), the maximum residual MB in all three fruits was less than 5.0 p/m, and after 7 days it was less than 0.30 p/m. As the fumigation temperature increased, the rate of desorption increased, which may be explained by the greater volatility of MB at the higher temperatures. Although plums had the lowest inorganic residues, they retained organic bromide longer, which may account for the fact that plums generally were injured more than peaches or nectarines.

Organic and inorganic bromide residues were not significantly different in hydrocooled or aircooled fruit, nor in fruit from packinghouse lots or field-run lots.

Phytotoxicity

Symptoms. Injury usually appeared as a slight to severe browning of the surface of the fruit, as slight to severe pitting, or as a mottling or discoloration. Some unfumigated control lots of fruit developed a slight browning or mottling, which was indistinguishable from MB injury and probably resulted from mechanical injuries that occurred during harvesting and packinghouse handling. In general, peaches were most tolerant of the fumigation treatments, nectarines were intermediate, and plums were the least tolerant, although individual cultivars within each kind of fruit differed greatly in tolerance.

Peaches typically have light tan to brown blotchy areas on their surfaces when injured by MB. Slightly injured areas frequently are not sunken, but shallow sinking may occur in severely injured fruit (fig. 2).

Nectarines become deeply pitted when injured by MB. The pitting generally was more severe near the suture than on the remaining surface of the fruit. Fantasia and Fairlane exhibited this type of injury (fig. 3). On such cultivars as Flamekist that tend to have a natural russeting, the

Table 2—Inorganic bromide residues in fumigated peaches, nectarines, and plums after 2 hr aeration

Type of fruit	Temperature during fumigation	Residue after 2 hr fumigation at indicated dosage of methyl bromide (g/m^3) 0	32	48	64	80
	°C	*Parts per million*				
Peaches[1]	4.5	<2	4.5 ± 1.9	9.9 ± 1.7	8.2 ± 4.0	15.0 ± 3.7
	15.5	<2	5.2 ± 2.0	6.1 ± 3.0	9.1 ± 3.9	9.8 ± 4.6
	26.5	<2	4.6 ± 2.0	6.7 ± 1.9	8.4 ± 2.4	9.5 ± 3.2
Nectarines[2]	4.5	<2	2.8 ± 1.8	5.2 ± 1.4	6.8 ± 2.9	8.4 ± 4.1
	15.5	<2	3.9 ± 1.9	5.8 ± 3.3	7.8 ± 4.0	9.6 ± 3.4
	26.5	<2	3.3 ± 1.4	5.0 ± 1.6	6.7 ± 1.8	8.3 ± 2.7
Plums[3]	4.5	<2	<2	3.1 ± 1.5	3.3 ± 2.3	4.4 ± 1.7
	15.5	<2	3.6 ± 1.6	5.1 ± 1.5	6.0 ± 2.2	7.1 ± 2.4
	26.5	<2	4.0 ± 2.1	5.2 ± 2.2	7.1 ± 1.8	4.8 ± 2.6

[1]Data represent average residues ± standard deviations in packinghouse lots and field-run lots of Fayette and Coronet peaches.

[2]Data represent average residues ± standard deviations in packinghouse lots and field-run lots of Summer Grand, Fantasia, Fairlane, and Red Diamond nectarines.

[3]Data represent average residues ± standard deviations in packinghouse lots and field-run lots of Santa Rosa, Casselman, Friar, and Laroda plums.

russeting became more intense and the ground color turned tan to brown in injured fruit (fig. 4).

Green plums, such as Kelsey, had dark brown spots or blotches when injured by MB (fig. 5). Extensive tan to brown blotches developed on the surface of injured Casselman plums. Dark purple spots developed on injured red Santa Rosa and Red Beaut plums, but these spots tended to disappear as the fruit ripened and turned uniformly purple (fig. 6).

Weight loss. Weight loss from nectarines, peaches, and plums was not significantly affected by the fumigation treatments under these experimental conditions. At the first examination (after 2 weeks at 2.5°C), plums had lost only 2.2 percent of their original weight, while nectarines had lost 3.0 percent and peaches, 4.3 percent. At the second examination (after 2 additional days at 21°), the respective weight losses were 3.8, 4.5, and 6.1 percent.

Temperature during fumigation vs. phytotoxicity. The level of MB injury in peaches was so low that differences due to temperature were not apparent. Nectarines, however, were injured most when fumigated at low temperature (4.5°C) and least when fumigated at high temperature (26.5°C) (table 6).

Plums also were injured less when fumigated at high, rather than at low temperature (table 7). The temperature effect was most pronounced in Kelsey plums. Injury was at a lower level in Friar than in Kelsey. At 48 g/m^3 MB, Red Beaut, Casselman, and Santa Rosa had little or no symptoms of injury.

Table 3—Organic bromide residues in fumigated peaches after 2 hr aeration and after 2 and 7 days storage at 2.5°C[1]

Time after fumigation	Temperature during fumigation	Residue after 2 hr fumigation at indicated dosage of methyl bromide (g/m^3)					
		0	16	32	48	64	80
	°C	*Parts per million*					
2 hr	4.5	0.04 ± 0.04	—	—	12.58 ± 11.42	13.72 ± 7.13	15.14 ± 9.62
	15.5	0.13 ± 0.13	—	18.35 ± 7.88	25.55 ± 9.87	37.55 ± 15.50	—
	26.5	<0.01	3.5 ± 3.2	5.22 ± 1.68	5.61 ± 5.47	—	—
2 days	4.5	0.08 ± 0.08	—	—	0.11 ± 0.14	0.13 ± 0.16	0.17 ± 0.15
	15.5	0.08 ± 0.09	—	0.04 ± 0.06	0.21 ± 0.26	0.15 ± 0.16	—
	26.5	0.02	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.02	—	—
7 days	4.5	0.03 ± 0.03	—	—	0.04 ± 0.04	0.02 ± 0.02	0.03 ± 0.03
	15.5	0.02 ± 0.01	—	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.02	—
	26.5	<0.01	<0.01	<0.01	<0.01	—	—

[1]Data represent average residues ± standard deviations in packinghouse lots and field-run lots of Red Top and O'Henry peaches.

Note: Dashes indicate no data.

Table 4—Organic bromide residues in fumigated nectarines after 2 hr aeration and after 2 and 7 days storage at 2.5°C[1]

Time after fumigation	Temperature during fumigation	Residue after 2 hr fumigation at indicated dosage of methyl bromide (g/m^3)					
		0	16	32	48	64	80
	°C	*Parts per million*					
2 hr	4.5	0.02 ± 0.03	—	—	22.43 ± 6.31	28.10 ± 9.74	31.41 ± 5.14
	15.5	0.02 ± 0.03	—	13.82 ± 4.67	20.28 ± 9.38	26.71 ± 10.49	—
	26.5	0.02 ± 0.02	4.00 ± 2.26	6.34 ± 3.04	10.27 ± 7.34	—	—
2 days	4.5	0.01 ± 0.01	—	—	0.04 ± 0.10	0.07 ± 0.08	0.11 ± 0.25
	15.5	0.02 ± 0.03	—	0.03 ± 0.04	0.14 ± 0.30	0.05 ± 0.07	—
	26.5	0.03 ± 0.04	0.04 ± 0.06	0.06 ± 0.09	0.07 ± 0.09	—	—
7 days	4.5	0.02 ± 0.02	—	—	0.01 ± 0.02	<0.01	<0.01
15.5	0.02 ± 0.01	0.02 ± 0.01	—	<0.01	0.01 ± 0.01	<0.01	—
	26.5	0.02 ± 0.03	0.02 ± 0.03	0.02 ± 0.03	0.02 ± 0.03	—	—

[1]Data represent average residues ± standard deviations in packinghouse lots and field-run lots of May Grand, Spring Red, Fantasia, and Red Diamond nectarines.

Note: Dashes indicate no data.

Table 5—Organic bromide residues in fumigated plums after 2 hr aeration and after 2 and 7 days storage at 2.5°C[1]

Time after fumigation	Temperature during fumigation	Residue after 2 hr fumigation at indicated dosage of methyl bromide (g/m^3)					
		0	16	32	48	64	80
	°C	*Parts per million*					
2 hr	4.5	0.02 ± 0.03	—	—	26.51 ± 14.96	31.17 ± 15.06	33.27 ± 14.05
	15.5	0.02 ± 0.02	—	17.99 ± 9.38	27.41 ± 13.55	26.70 ± 9.70	—
	26.5	0.01 ± 0.02	10.43 ± 3.08	18.31 ± 7.37	23.66 ± 7.00	—	—
2 days	4.5	0.02 ± 0.02	—	—	0.50 ± 0.44	0.68 ± 0.66	0.93 ± 0.97
	15.5	0.03 ± 0.02	—	0.93 ± 1.11	0.96 ± 1.05	1.23 ± 0.96	—
	26.5	0.03 ± 0.04	0.22 ± 0.24	0.44 ± 0.52	0.77 ± 0.78	—	—
7 days	4.5	0.04 ± 0.07	—	—	0.05 ± 0.07	0.06 ± 0.07	0.06 ± 0.07
	15.5	0.01 ± 0.02	—	0.02 ± 0.02	0.01 ± 0.02	0.03 ± 0.03	—
	26.5	0.02 ± 0.03	0.02 ± 0.03	0.02 ± 0.02	0.02 ± 0.02	—	—

[1]Data represent average residues ± standard deviations in packinghouse lots and field-run lots of Red Beaut, Kelsey, Santa Rosa, and Friar plums.

Note: Dashes indicate no data.

Phytotoxicity vs. concentration of MB and temperature. When treated for 2 hr, the various MB treatments did not affect injury of peaches significantly, but did affect the percentage of injured nectarines and plums. When nectarines that had gone through the packinghouse were fumigated (table 8), the percentage of injured fruit was greater in treatments in which the concentration of MB was high and the temperatures were low than in those with lower concentrations and higher temperatures. Cultivars of nectarines differed greatly in the percentage of fruit injured. May Grand and Fantasia had little or no injury, whereas Spring Red and Red Diamond were intermediate in injury. The high incidence of injury in Flamekist was not all due to fumigation, however, since the unfumigated control lot also was injured. If the injury caused by factors other than fumigation were not included, then fumigation injury in Flamekist would be comparable to that in the cultivars that were moderately susceptible to injury.

Injury to packinghouse lots of plums also increased with increasing MB concentration and lower temperatures (table 9). Most of the injury occurred in Kelsey and Friar, however, and little or no injury occurred in Santa Rosa

Figure 2.—Symptoms of methyl bromide injury to Fayette peach (dosage = 80 g/m^3, 2 hr, 4.5°C).

Figure 3.—Symptoms of methyl bromide injury to Fantasia nectarine (dosage = 80 g/m^3, 2 hr, 4.5°C).

Figure 4.—Symptoms of methyl bromide injury to Flamekist nectarine (dosage = 64 g/m³, 2 hr, 15.5°C).

Figure 5.—Symptoms of methyl bromide injury to Kelsey plum (dosage = 48 g/m³, 2 hr, 26.5°C).

Figure 6.—Symptoms of methyl bromide injury to Red Beaut plums (dosage = 80 g/m³, 2 hr, 4.5°C).

and Casselman, except at the highest concentration of MB. Red Beaut developed dark spots that were apparent on unripe fruit, but disappeared as the fruit ripened and became uniformly dark.

The effect of fumigation on ripening of nectarines and peaches (table 10) was indicated primarily by changes in the firmness of fruit treated at various MB concentrations and temperatures. Since the firmness of nectarines and peaches was about the same when fumigated at 4.5° or 15.5°C with a given concentration of MB (48 g/m³), differences in ripening within this temperature range appeared to be due primarily to concentration of fumigant. When fumigated at 26.5°, however, nectarines and peaches were about 2.0 lb (0.9 kg) softer than they were at the lower treatment temperatures. The highest fumigation temperature appears, therefore, to mitigate the retarding effect of high MB concentrations on ripening of these fruit. Fruit treated with 16 g/m³ MB were slightly softer when later evaluated than untreated fruit; however, fruit fumigated with 32 g/m³ MB or higher did not soften as much as the control lots. This retardation of ripening may be beneficial for export shipments.

The ripening of plums also was affected by the concentration of MB during fumigation (table 11). Since plums fumigated at all three temperatures with a given concentration of MB (48 g/m³) had about the same firmness, differences in ripening rate appeared to be primarily due to concentration of fumigant. As the concentration of MB was increased during fumigation, the percentage of relatively ripe fruit decreased. Ripening was evidenced primarily by color changes in the fruit, but also by firmness. Control fruit softened more during holding than fruit fumigated with 32 g/m³ MB or more. Soluble solids content was not affected by fumigation.

Packinghouse handling vs. phytotoxicity. Fruit that had gone through packinghouse handling generally had a higher incidence of fumigation injury than field-run fruit (table 12). In nectarines, the difference was most evident in Flamekist and Red Diamond. In plums, the packinghouse lot of Kelsey and Friar had more injury than the field-run lot.

Discussion and Conclusions

Generally, peaches were the most tolerant of MB fumigation among the stone fruits studied; some plum cultivars were the least tolerant of fumigation, although individual cultivars differed greatly. Tolerance was negatively correlated with sorption, since sorption during fumigation was highest in peaches and lowest in plums (fig. 1). Inorganic bromide residues also were lower in plums than in nectarines or peaches. Organic bromide residues, however, were higher in plums than in the other two fruits; plums retained organic bromide longer than the other fruits, which may account for the fact that plums generally were injured more than peaches or nectarines.

Of the nectarine cultivars tested, May Grand and Fantasia were most tolerant of MB, Flamekist appeared to be the

Table 6—Phytotoxicity in nectarines fumigated for 2 hr at various temperatures with methyl bromide (48 g/m^3)

Nectarine cultivar	Percentage of injured fruit when fumigated at indicated temperature		
	4.5°C	15.5°C	26.5°C
		Percent	
Fantasia	1	0	0
Flamekist	53	50	46
May Grand	[1]0	0	0
Red Diamond	28	18	0
Spring Red	4	1	2
Average	17	14	9

[1]Data include first and second examinations of packinghouse lots only (100 fruit of each cultivar).

Table 7—Phytotoxicity in plums fumigated for 2 hr at various temperatures with methyl bromide (48 g/m^3)

Plum cultivar	Percentage of injured fruit when fumigated at indicated temperature		
	4.5°C	15.5°C	26.5°C
		Percent	
Casselman	0	0	0
Friar	21	12	18
Kelsey	59	41	17
Red Beaut	[1]0	0	0
Santa Rosa	0	6	0
Average	16	12	7

[1]Data include first and second examinations of packinghouse lots only (100 fruit of each cultivar).

Table 8—Phytotoxicity in nectarines fumigated for 2 hr with methyl bromide (MB) at various dosages and temperatures

Nectarine cultivar	Percentage of injured fruit when fumigated with indicated dosage of MB (g/m^3)					
	0	[1]16	[2]32	[3]48	[4]64	[5]80
			Percent			
Fantasia	0	0	0	<1	4	29
Flamekist	48	30	51	49	52	62
May Grand	[6]0	0	0	0	0	0
Red Diamond	0	0	3	15	22	45
Spring Red	2	15	2	2	6	12
Average	10	9	11	13	17	30

[1]26.5°C; 100 fruit of each cultivar.
[2]15.5° and 26.5°C; 200 fruit of each cultivar.
[3]4.5°, 15.5°, and 26.5°C; 300 fruit of each cultivar.
[4]4.5° and 15.5°C; 200 fruit of each cultivar.
[5]4.5°C; 100 fruit of each cultivar.
[6]Data include first and second examinations of packinghouse lots only.

Table 9—Phytotoxicity in plums fumigated for 2 hr with methyl bromide (MB) at various dosages and temperatures

Plum cultivar and examination	Percentage of injured fruit when fumigated with indicated dosage of MB (g/m^3)					
	0	[1]16	[2]32	[3]48	[4]64	[5]80
			Percent			
After 14 days at 2.5°C:						
Casselman	0	0	0	0	4	5
Friar	5	0	4	21	26	3
Kelsey	0	0	4	28	59	90
Red Beaut	[6]0	0	1	34	52	96
Santa Rosa	0	0	1	5	14	9
Average	1	0	2	18	31	41
After 2 additional days at 21°C:						
Casselman	0	0	0	0	0	3
Friar	4	2	11	13	3	2
Kelsey	0	0	10	49	73	100
Red Beaut	0	0	0	0	0	0
Santa Rosa	0	0	0	0	0	0
Average	1	0	4	12	15	21

[1]26.5°C; 100 fruit of each cultivar.
[2]15.5°and 26.5°C; 200 fruit of each cultivar.
[3]4.5°, 15.5°, and 26.5°C; 300 fruit of each cultivar.
[4]4.5° and 15.5°C; 200 fruit of each cultivar.
[5]4.5°C; 100 fruit of each cultivar.
[6]Packinghouse lots only.

Table 10—Ripening of nectarines and peaches[1] fumigated for 2 hr with methyl bromide (MB) at various dosages and temperatures

MB dosage (g/m^3)	Temperature[2]	Nectarines[3]			Peaches[4]		
		Average fruit firmness		Soluble solids content	Average fruit firmness		Soluble solids content
		Lb	*(Kg)*	*Percent*	*Lb*	*(Kg)*	*Percent*
0	(1)	4.0	(1.8)	9.8	2.7	(1.2)	10.8
16	(2)	2.8	(1.3)	10.0	2.2	(1.0)	10.7
32	(3)	4.4	(2.0)	9.9	2.9	(1.3)	11.0
48	(1)	4.9	(2.2)	10.0	3.4	(1.5)	10.7
64	(4)	6.1	(2.8)	9.9	4.6	(2.1)	10.9
80	(5)	5.7	(2.6)	10.0	4.9	(2.2)	10.6

[1]Data include first and second examinations of packinghouse and field-run lots.
[2](1) = 4.5°, 15.5°, and 26.5°C; 600 fruit of each cultivar.
(2) = 26.5°C; 200 fruit of each cultivar.
(3) = 15.5° and 26.5°C; 400 fruit of each cultivar.
(4) = 4.5° and 15.5°C; 400 fruit of each cultivar.
(5) = 4.5°C; 200 fruit of each cultivar.
[3]May Grand, Flamekist, Spring Red, Fantasia, and Red Diamond.
[4]Springcrest, Red Top, and O'Henry.

Table 11—Ripening of plums[1] fumigated for 2 hr with methyl bromide (MB) at various dosages and temperatures

MB dosage (g/m^3)	Temperature[2]	Average fruit firmness[3]		Average soluble solids content[4]	Percent fruit[3] in indicated color class[5]		
					I	II	III
		Lb	*(Kg)*	*Percent*		*Percent*	
0	(1)	4.1	(1.9)	12.3	2.2	52.3	46.3
16	(2)	4.1	(1.9)	12.5	4.1	47.4	48.9
32	(3)	4.6	(2.1)	13.9	4.4	53.3	40.0
48	(1)	4.7	(2.1)	12.4	7.4	54.4	38.3
64	(4)	5.4	(2.5)	12.4	9.7	53.3	36.4
80	(5)	5.2	(2.4)	12.2	12.6	51.7	36.0

[1]Data include first and second examinations of packinghouse and field-run lots.
[2](1) = 4.5°, 15.5°, and 26.5°C; 600 fruit of each cultivar.
(2) = 26.5°C; 200 fruit of each cultivar.
(3) = 15.5° and 26.5°C; 400 fruit of each cultivar.
(4) = 4.5° and 15.5°C; 400 fruit of each cultivar.
(5) = 4.5°C; 200 fruit of each cultivar.
[3]Santa Rosa, Casselman, and Friar.
[4]Santa Rosa, Casselman, Red Beaut, and Kelsey.
[5]I = least color development, III = most color development.

Table 12—Percentage of nectarines, peaches, and plums injured when fumigated for 2 hr with methyl bromide (48 g/m^3)

Fruit	Percentage of injured fruit when fumigated at indicated stage of handling	
	After packing	Field bins
	Percent	
Nectarine:		
May Grand	[1]0	0
Spring Red	2	7
Fantasia	0	1
Flamekist	49	0
Red Diamond	15	5
Average	13	3
Peach:		
O'Henry	0	0
Red Top	1	1
Springcrest	3	2
Average	1	1
Plum:		
Red Beaut	17	
Santa Rosa	2	3
Kelsey	39	32
Casselman	0	0
Friar	17	5
Average	15	13

[1]Data include first and second examinations of lots fumigated at 4.5°, 15.5°, and 26.5°C (300 fruit).

least tolerant. The high incidence of injury in the control suggests that part of the observed injury may be due to other factors. Spring Red and Red Diamond were intermediate in injury. Among the peach cultivars, Springcrest, Red Top, and O'Henry were most tolerant of MB, and Fayette and Coronet were moderately tolerant. Of the plum cultivars, Red Beaut, Santa Rosa, and Casselman were more tolerant, and Kelsey and Friar were less tolerant of MB fumigation.

Weight loss was not significantly affected by the fumigation treatments, although one might expect that injured fruit would lose more weight than uninjured fruit. No differences could be detected in weight loss as a result of fumigation treatment, but differences were apparent among the various kinds of fruit, that is, peaches lost the most weight, plums the least, and nectarines were intermediate.

Temperature of fruit while being fumigated affected phytotoxicity responses. More injury developed during subsequent holding of fruit fumigated at low temperature (4.5°C) than in those treated at high temperature (26.5°).

Increases in the dosages of MB generally were accompanied by increased phytotoxicity in those cultivars that were least tolerant of fumigation. Most cultivars, however, could tolerate 32 or 48 g/m^3 for 2 hr without objectionable injury. Fruit exposed to the highest dosages of fumigant ripened more slowly than those not fumigated or those treated with lower dosages of fumigant. The effect on ripening of plums appeared to be primarily due to concentration, rather than temperature during fumigation. In nectarines and peaches, increased MB concentrations also slowed ripening, but the highest fumigation temperature (26.5°C) appeared to mitigate retardation of ripening. Ripening was measured by the firmness of all three fruits and by color development in plums.

Packinghouse handling also reduced the tolerance of fruit to fumigation treatments. Phytotoxicity was greater in packinghouse lots of fruit than in field-run lots selected before the fruit was washed, brushed, waxed, or treated with a fungicide.

The effects of temperature and packinghouse handling suggest that fruit should be fumigated shortly after harvest and before packing and cooling. This procedure would be most practical if all the fruit going through the packing facility had to be treated to control quarantine insects, such as the Mediterranean fruit fly (*Ceratitis capitata* Wied.). If only a relatively small portion of the fruit being handled in the packinghouse required fumigation, for example, only that for export, then fumigating late in the handling sequence may be more practical, even though the potential for injury might be greater. Fruit fumigated after packing would not require special handling all the way through the packinghouse and prompt cooling would favor quality maintenance. Such a procedure would require the development of effective, nonphytotoxic fumigation procedures at low temperatures and study of the effects of packaging materials on efficacy and phytotoxicity. Large-scale fumigations that approximate commercial conditions need to be conducted before the results of laboratory tests can be applied.

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Appendix

Appendix Table 1—Inorganic bromide residues in Fayette and Coronet peaches fumigated with methyl bromide (MB)

Cultivar	Temperature during fumigation	Residue after fumigation at indicated concentration of MB (g/m³)[1]				
		0	32	48	64	80
	°C	Parts per million				
Fayette	4.5	<2	5.1 ± 2.2	10.6 ± 1.5	10.2 ± 4.7	17.3 ± 3.4
	15.5	<2	6.2 ± 2.2	8.2 ± 2.7	11.6 ± 4.1	13.1 ± 4.1
	26.5	<2	3.4 ± 1.5	6.8 ± 1.4	9.1 ± 1.9	8.2 ± 1.5
Coronet	4.5	<2	3.8 ± 1.6	9.2 ± 1.6	6.2 ± 1.6	12.6 ± 2.2
	15.5	<2	4.1 ± 1.3	3.9 ± 0.9	6.5 ± 0.7	6.5 ± 2.0
	26.5	<2	5.8 ± 1.6	6.6 ± 2.6	7.7 ± 2.9	10.9 ± 4.0

[1]Data represent means of 3 replications per cultivar ± standard deviation. Fruit fumigated 2 hr followed by 2 hr of aeration.

Appendix Table 2—Inorganic bromide residues in Summer Grand, Fantasia, Fairlane, and Red Diamond nectarines fumigated with methyl bromide (MB)

Cultivar	Temperature during fumigation	Residue after fumigation at indicated concentration of MB (g/m³)[1]				
		0	32	48	64	80
	°C	Parts per million				
Summer Grand	4.5	<2	4.6 ± 0.9	5.0 ± 1.5	8.7 ± 2.0	8.3 ± 0.7
	15.5	<2	3.6 ± 0.6	4.5 ± 1.4	5.8 ± 1.8	8.1 ± 1.5
	26.5	<2	3.0 ± 0.8	4.6 ± 0.8	5.7 ± 1.7	6.6 ± 2.0
Fantasia	4.5	<2	2.4 ± 1.3	6.2 ± 1.2	6.6 ± 1.8	10.2 ± 3.4
	15.5	<2	1.6 ± 1.6	2.2 ± 2.2	2.8 ± 2.4	5.3 ± 1.8
	26.5	<2	2.3 ± 0.7	3.5 ± 0.7	4.6 ± 1.2	6.0 ± 1.3
Fairlane	4.5	<2	2.9 ± 2.5	5.4 ± 1.5	7.0 ± 4.8	9.2 ± 7.1
	15.5	<2	5.8 ± 1.4	8.2 ± 1.6	10.9 ± 1.2	13.6 ± 1.2
	26.5	<2	4.1 ± 2.2	6.0 ± 1.4	9.0 ± 1.1	11.9 ± 0.8
Red Diamond	4.5	<2	1.6 ± 0.7	4.3 ± 0.6	4.8 ± 0.6	6.0 ± 1.8
	15.5	<2	4.8 ± 1.0	8.8 ± 0.9	11.5 ± 0.4	11.3 ± 0.5
	26.5	<2	3.7 ± 0.8	5.8 ± 1.7	7.1 ± 0.5	8.7 ± 0.5

[1]Data represent means of 3 replications per cultivar ± standard deviation. Fruit fumigated 2 hr followed by 2 hr of aeration.

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Appendix Table 3—Inorganic bromide residues in Santa Rosa, Casselman, Friar, and Laroda plums fumigated with methyl bromide (MB)

Cultivar	Temperature during fumigation	Residue after fumigation at indicated concentration of MB (g/m^3)[1]				
		0	32	48	64	80
	°C	*Parts per million*				
Santa Rosa	4.5	<2	2.2 ± 0.4	2.6 ± 0.4	2.8 ± 0.5	3.9 ± 0.6
	15.5	<2	2	4.7 ± 1.6	4.3 ± 0.5	5.0 ± 1.5
	26.5	<2	4.5 ± 2.0	6.2 ± 1.1	7.1 ± 3.0	10.5 ± 1.7
Casselman	4.5	<2	0.4 ± 0.9	2.4 ± 2.3	4.4 ± 3.6	4.1 ± 2.1
	15.5	<2	4.5 ± 1.0	3.7 ± 1.2	5.7 ± 1.7	7.2 ± 2.5
	26.5	<2	4.1 ± 1.2	5.0 ± 1.8	7.1 ± 1.1	6.4 ± 1.2
Friar	4.5	<2	2.3 ± 0.6	2.8 ± 0.9	4.2 ± 1.7	4.7 ± 0.8
	15.5	<2	4.1 ± 0.9	5.4 ± 1.0	5.5 ± 1.1	7.2 ± 0.9
	26.5	<2	5.7 ± 1.0	6.9 ± 0.9	8.0 ± 0.9	10.8 ± 0.9
Laroda	4.5	<2	2	3.9 ± 2.0	2	4.6 ± 3.2
	15.5	<2	4.3 ± 1.0	5.7 ± 1.6	8.5 ± 2.8	9.0 ± 2.8
	26.5	<2	2	2.7 ± 2.1	6.3 ± 1.6	10.5 ± 4.3

[1]Data represent means of 3 replications per cultivar ± standard deviation. Fruit fumigated 2 hr followed by 2 hr of aeration.